Fiber orientations from diffusion MRI and histology in the macaque brain

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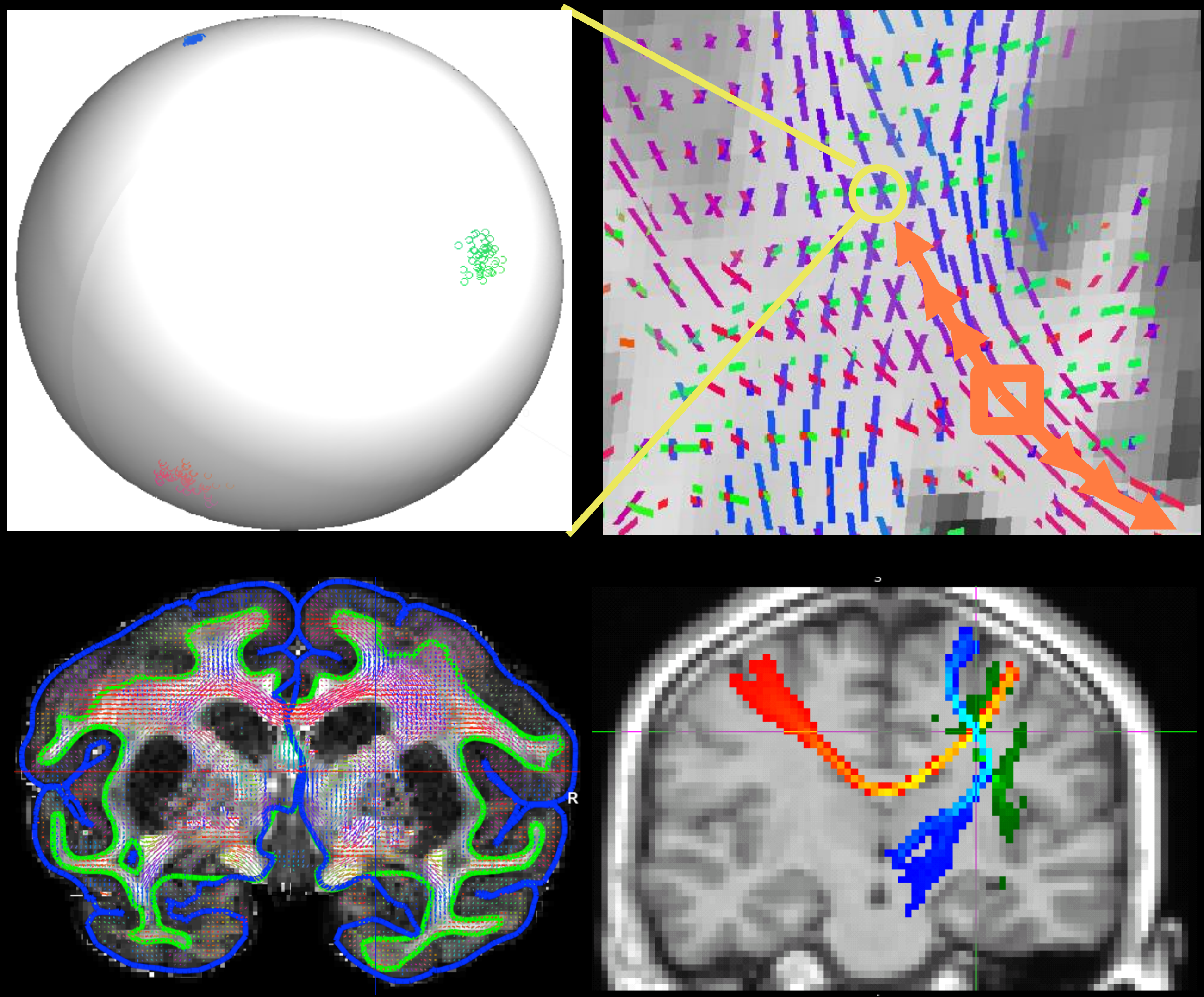
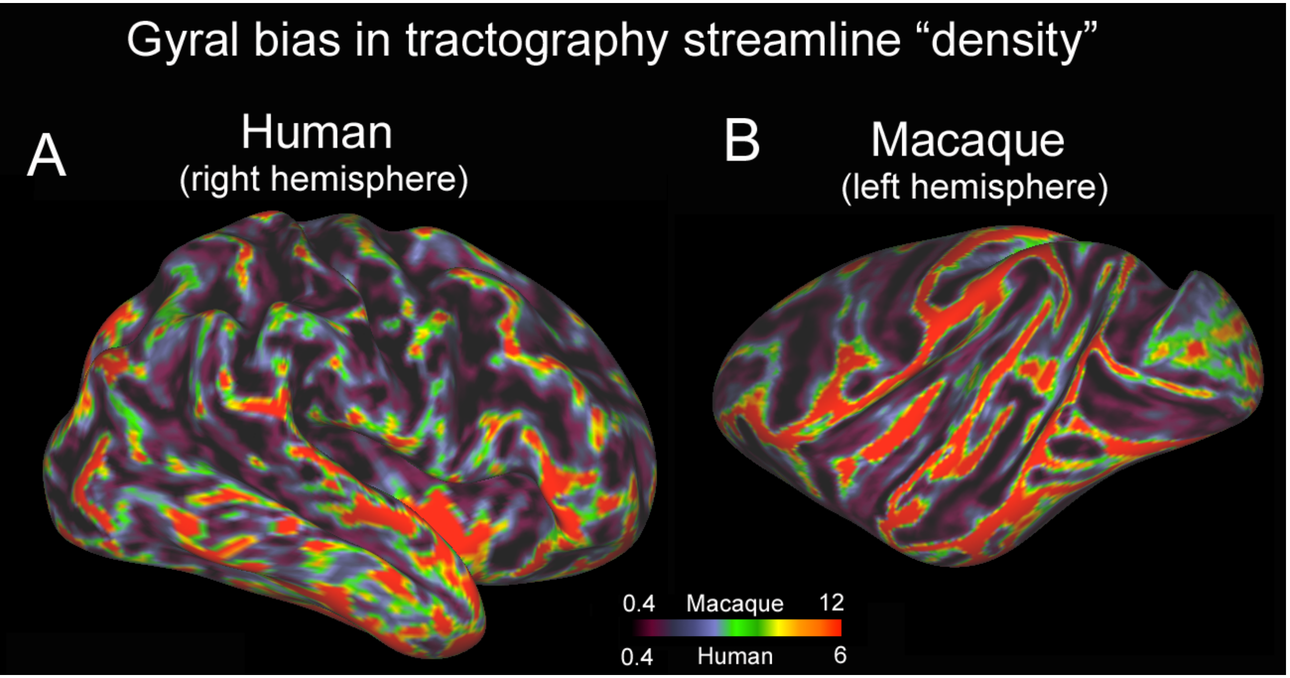
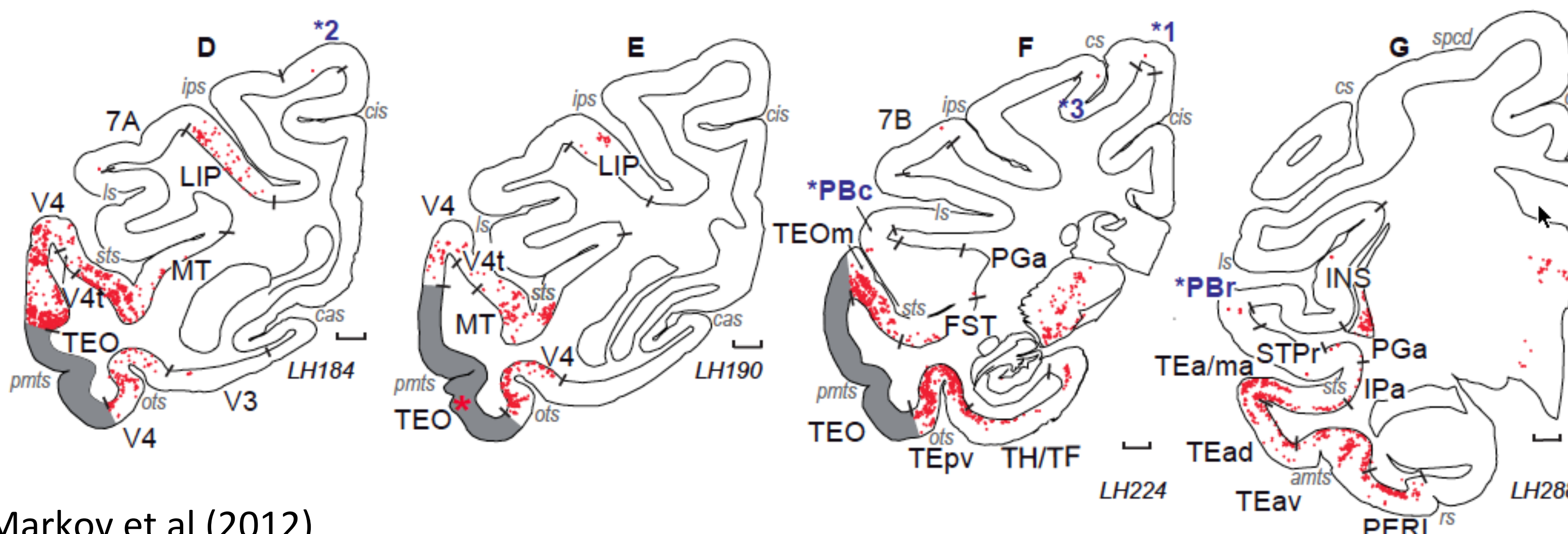
Diffusion MRI and tractography





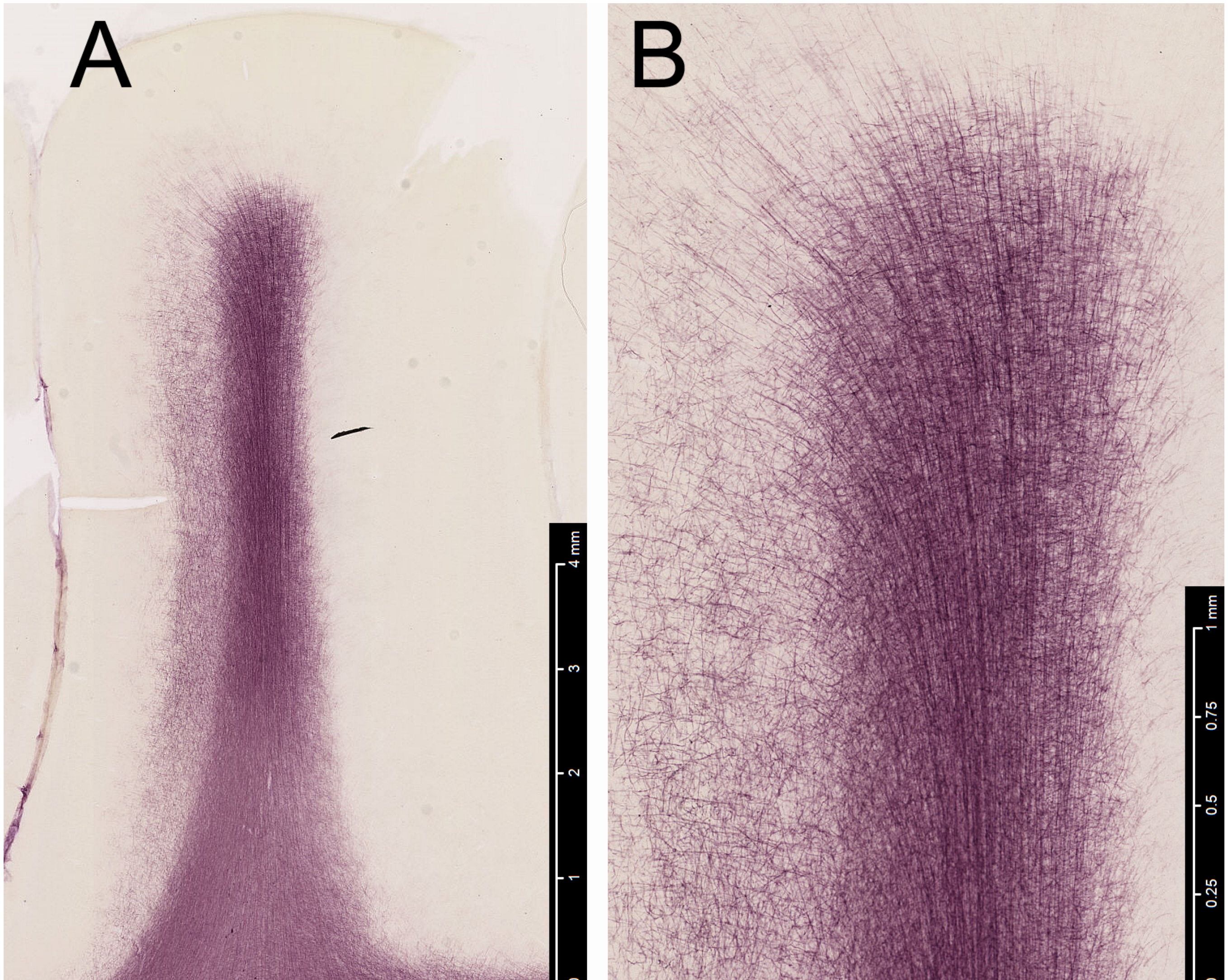
- Top : Streamline density maps from human and post-mortem macaque
- Bottom : Tracer injections from macaque

Van Essen et al (2013), in press



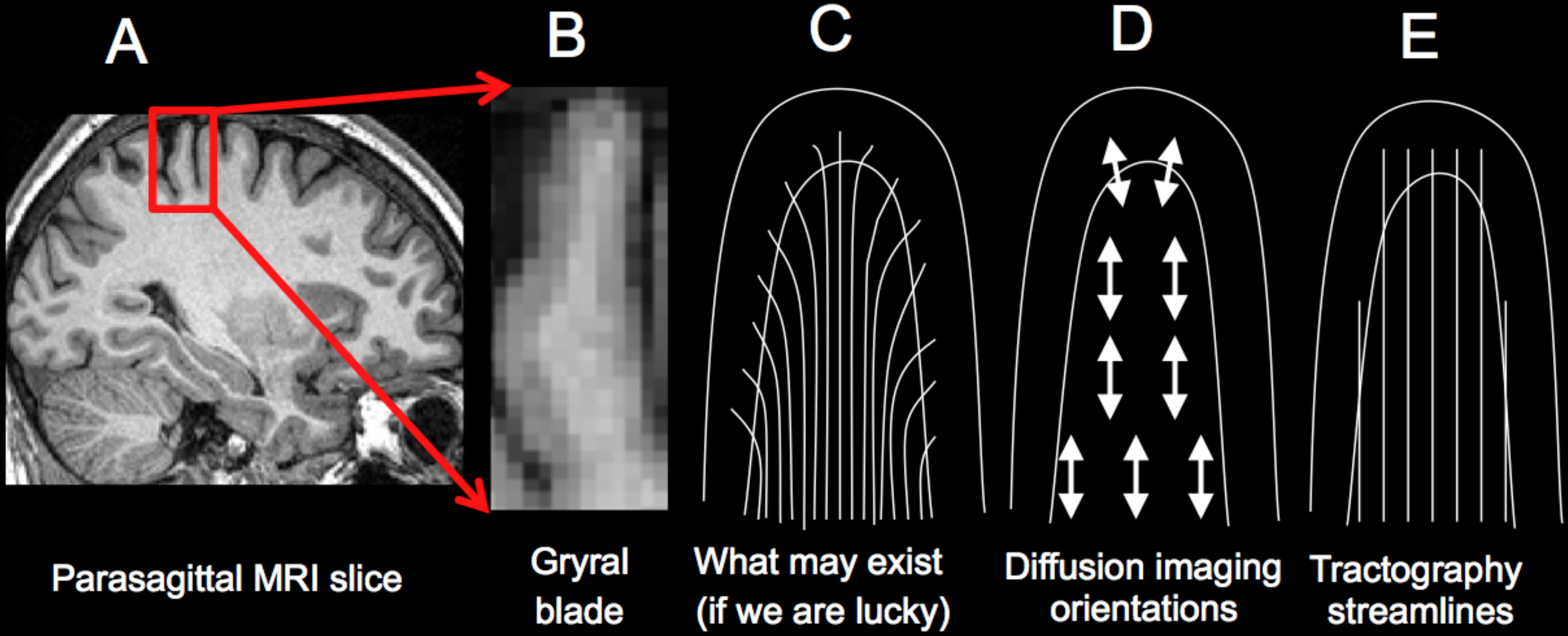
Markov et al (2012)

Insights from histology

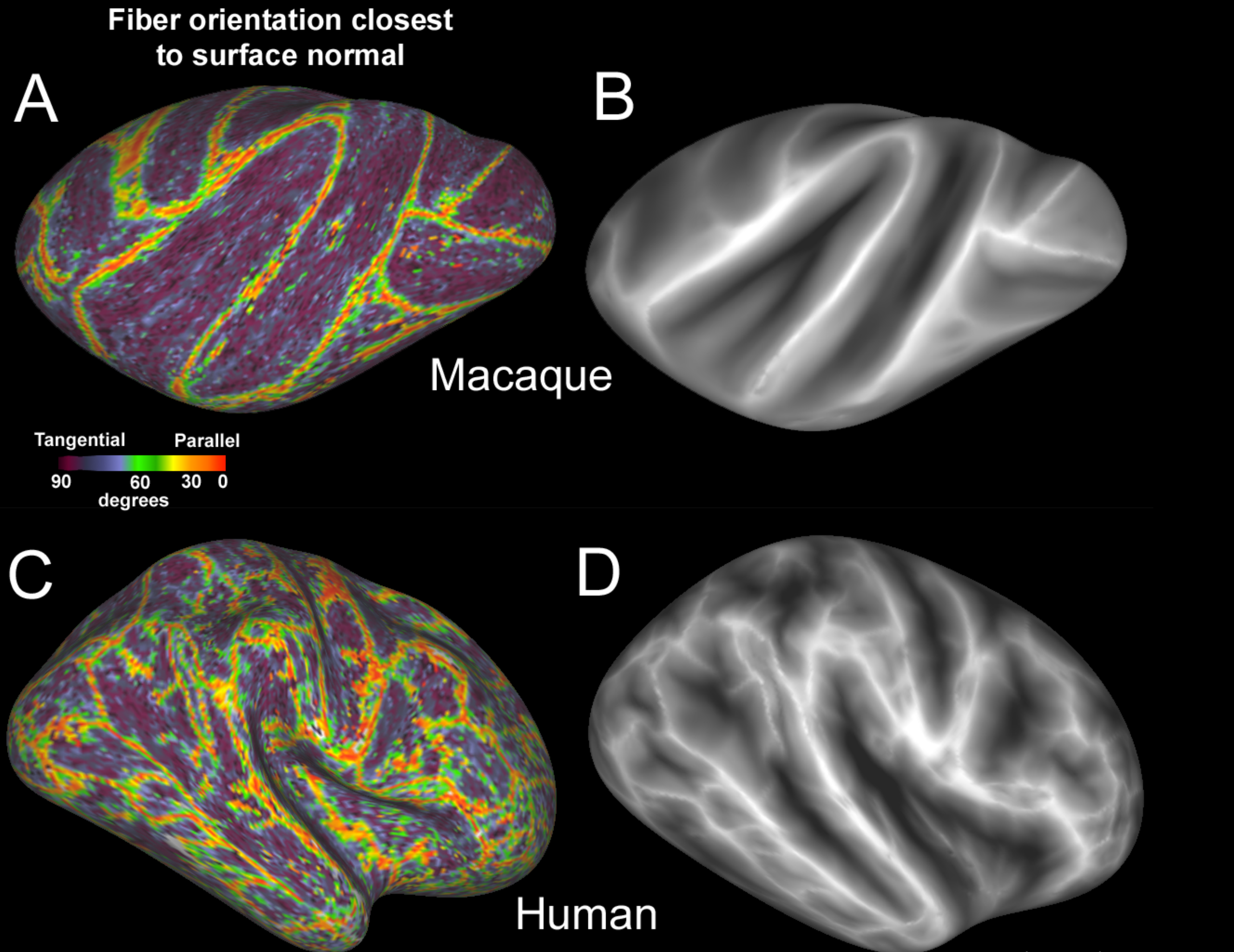


Van Essen et al (2013), in press

Tractography predictions

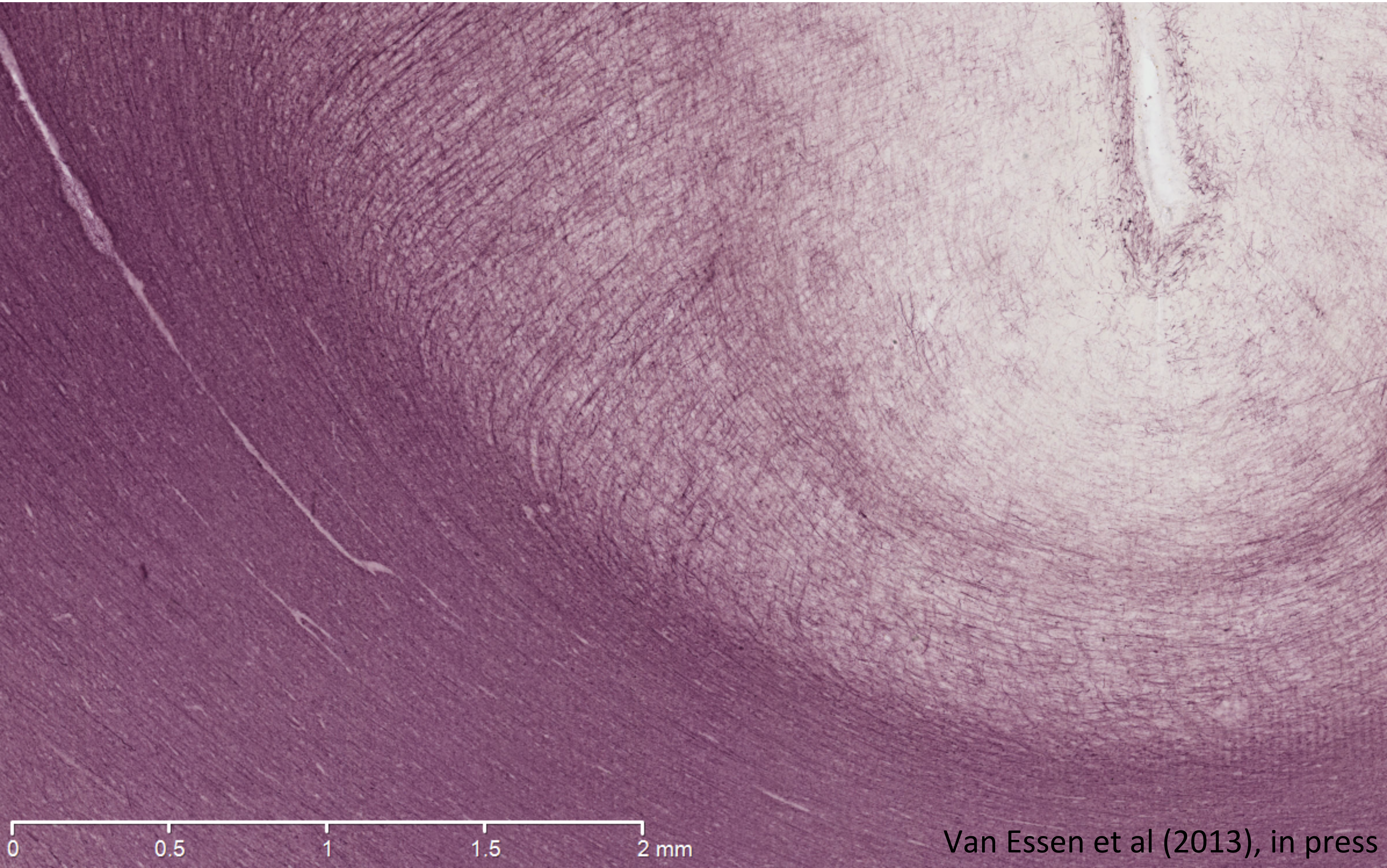


Van Essen et al (2013), in press



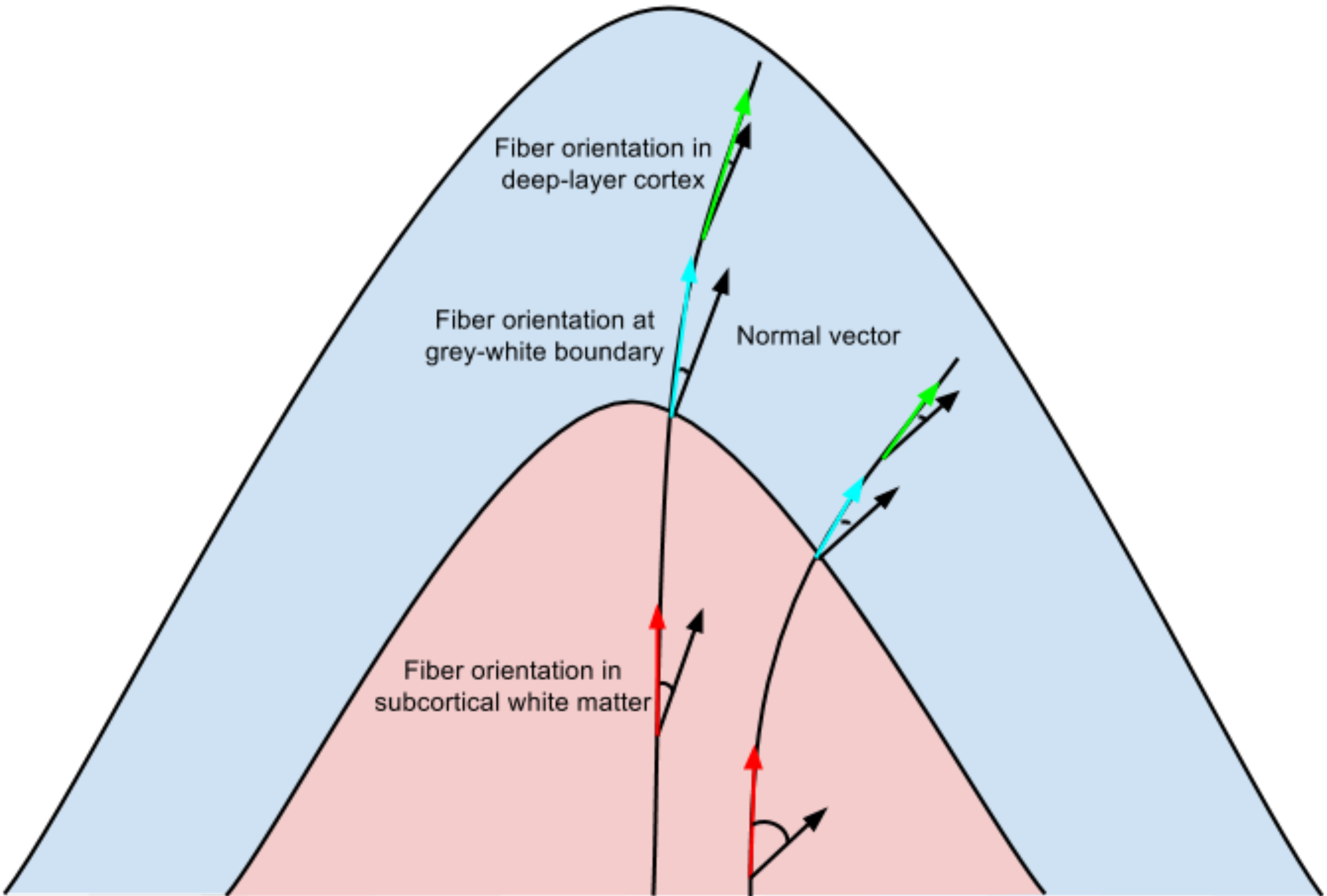
Van Essen et al (2013), in press

Insights from histology

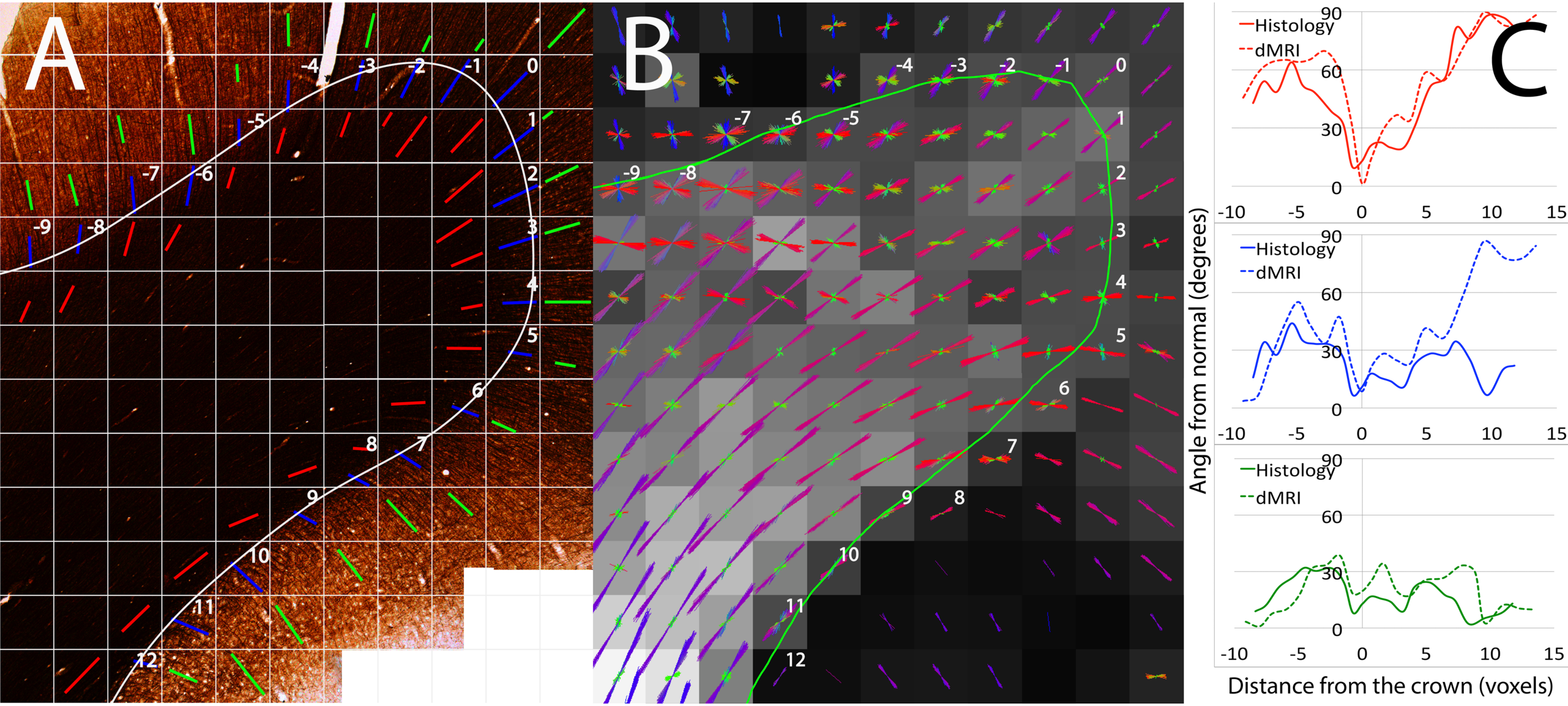


Van Essen et al (2013), in press

Fiber orientations near cortex



Comparing DTI and histology



Van Essen et al (2013), in press

Summary

- Diffusion MRI and tractography are powerful tools for generating connectomes
- However, they suffer from technical limitations, such as resolving gyral biases
- Tractography algorithms can be informed through histological data
- Fiber estimates can only be improved through better acquisition

Supplementary Slides

Imaging Methods

- Histology

  A postnatal day 6 macaque brain. Sections were immunostained with antibody to myelin basic protein (MBP, MAB395, Millipore) and scanned on a NanoZoomer 2 (Hamamatsu) scanning microscope equipped with Olympus lens at 20X (0.9225 um x 0.9225 um^2 resolution).

  A modified Gallyas myelin stained section from an adult macaque brain was also digitized in a similar fashion*.

- Post-mortem Diffusion MRI**

  A diffusion-weighted MRI dataset of a perfusion-fixed adult macaque brain was acquired using a 4.7 T Bruker scanner.

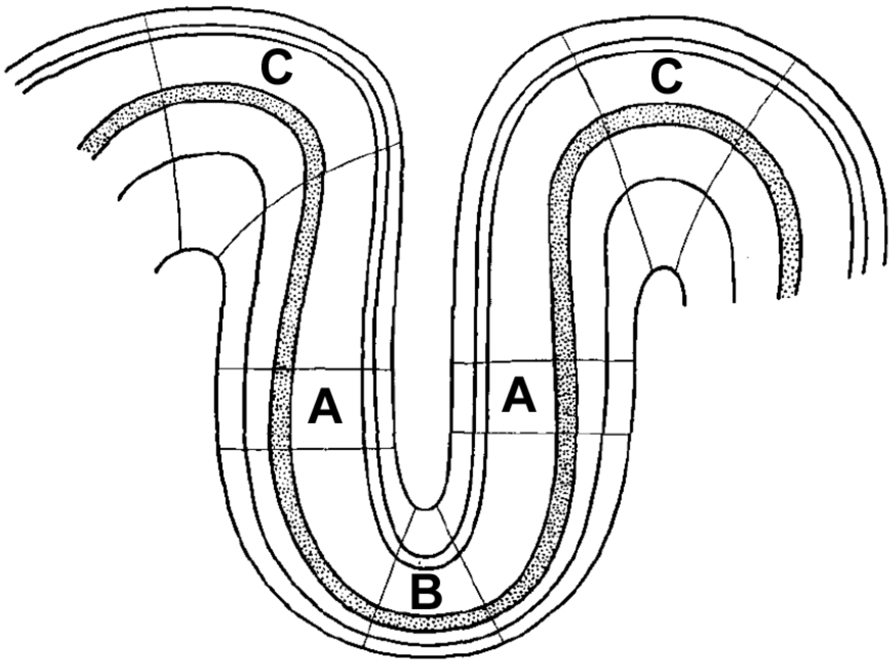
  Scans were performed using a 3D multi-shot, spin-echo sequence (with in-plane resolution 430 × 430 um^2, TE = 33 ms, TR = 350 ms)

  120 DW directions at b=8000 s/mm^2 , 17 b=0 s/mm^2 , 128 slices with a thickness of 430 um.

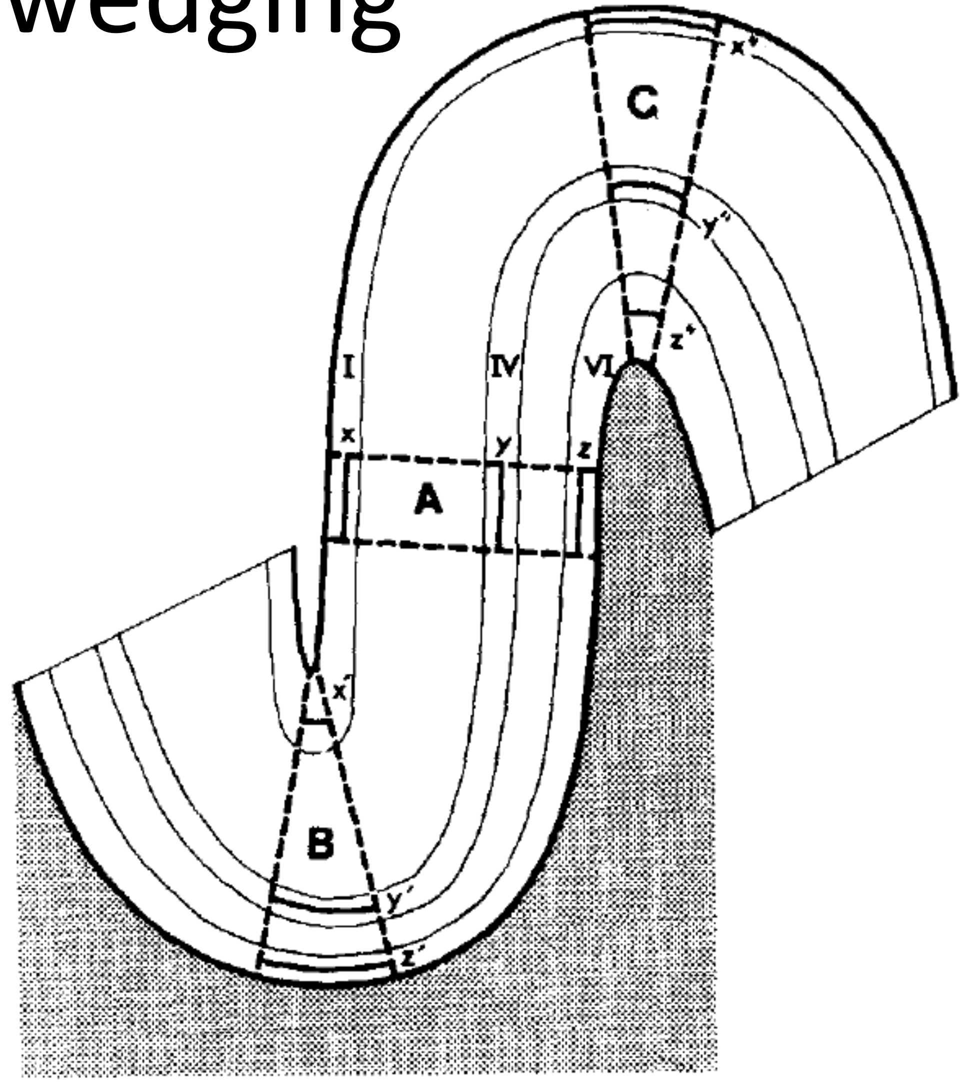
* Data are courtesy of JL Price, WashU, School of Medicine

** Data from [D'Arceuil et al, NeuroImage 35:553-565, 2007]

Cortical wedging

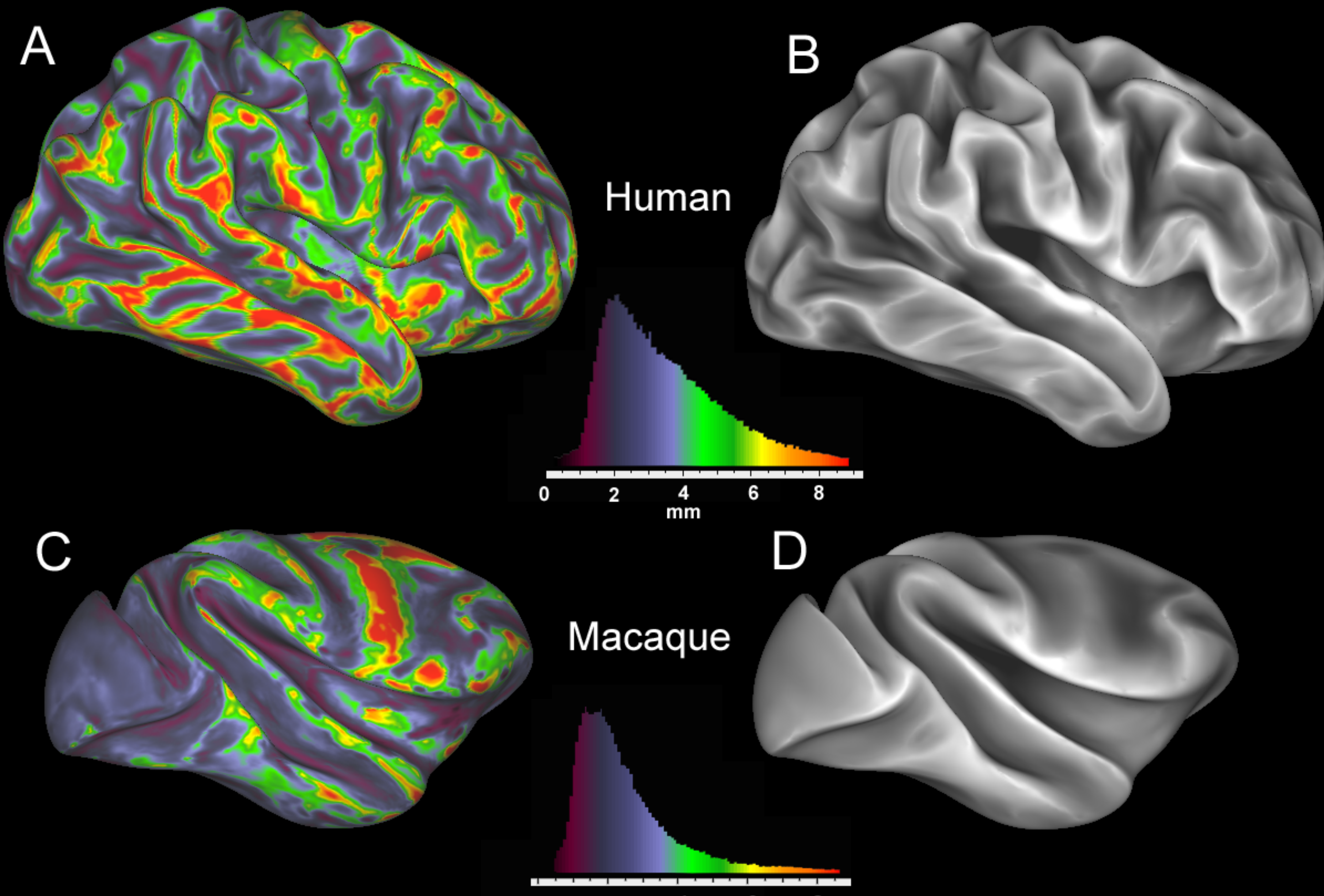


Bok (1929) (via Waehnert et al., 2013)



Van Essen and Maunsell, (1980)

Gyral vs sulcal wedges:
Cortical volume per unit area of gray/white surface

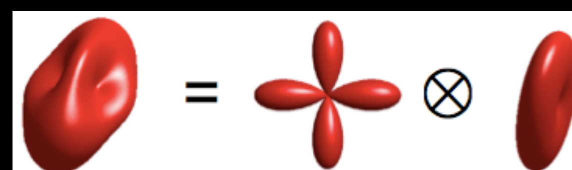


Van Essen et al (2013), in press

Parametric Spherical Deconvolution

- Assuming mono-exponential decay in q-space:
  [Behrens et al, MRM 2003], [Kaden et al, NeuroImage 2007]

$$S_k = S_0 \left[(1-f)\exp(-b_k d) + f \int_0^{2\pi}\int_0^{\pi} H(\theta,\phi)\exp(-b_k d(\mathbf{g}_k^T \mathbf{v})^2)\sin\theta d\theta d\phi \right]$$



- If the fODF is modelled as a Delta function (or sum of Delta functions), we get the *ball & stick model* [Behrens et al, MRM 2003, NeuroImage 2007]:

$$S_k = S_0 \left[(1-f)\exp(-b_k d) + f\exp(-b_k \boldsymbol{g}_k^T \boldsymbol{v})^2) \right]$$

Structure Tensor Analysis

Given an image $I(x, y)$ and its spatial gradient vector

$$\nabla I = [I_x \;\; I_y]^T$$

spatial partial derivative along y

(Gaussian smoothed)

The 2x2 *gradient tensor* is: $Q = \nabla I \cdot \nabla I^T = [q_{ij}]$

The 2x2 *structure tensor* is: $S = [s_{ij}], \quad s_{ij} = g_{\sigma,w} * \{q_{ij}\}$

Gaussian filter with window size w

and spatial scale σ

The eigenvector of the structure tensor associated with the smallest eigenvalue gives the *coherence* direction.

[Weickert, Int J Comp Vis, 1999]

Comparing DTI and Histology